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WIND-TUNNEL INVESTIGATION OF CONTROL-SURFACE CHARACTERISTICS

X - A 30-PERCENT-CHORD PLAIN FLAP WITH STRAIGHT CONTOUR

ON THE NACA 0015 AIRFOIL

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WIND-TUNNEL INVESTIGATION OF CONTROL-SURFACE CHARACTERISTICS

X - A 30-PERCENT-CHORD PLAIN FLAP WITH STRAIGHT CONTOUR ON THE NACA 0015 AIRFOIL

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SUMMARY

Force-test measurements in two-dimensional flow have been made in the NACA 4- by 6-foot vertical tunnel to determine the characteristics of an NACA 0015 airfoil equipped with a straight-contour plain flap having a chord 30 percent of the airfoil chord. The straight-contour plain flap differs from an ordinary plain flap in that the surfaces behind the hinge axis are flat instead of conforming to the basic airfoil contour. The results are presented in the form of aerodynamic section characteristics for several flap deflections and for a sealed and unsealed gap at the flap nose.

The slope of the lift curve of the NACA 0015 airfoil with the straight-contour plain flap was greater than for the same airfoil with an airfoil-contour plain flap of the same chord. The effectiveness of the straight-contour flap in producing increments of lift was slightly less with gap at the flap nose sealed and slightly greater with gap unsealed than the corresponding values for the airfoil-contour flap. For the straight-contour flap, the variation of the flap hinge moment with angle of attack and with flap deflection was larger than for the airfoil-contour flap. The straight-contour flap had approximately the same profile-drag characteristics as the airfoil-contour flap.

INTRODUCTION

The NACA has instituted an extensive investigation of the aerodynamic characteristics of various flap arrangements in an effort to determine the types best suited for control surfaces and to supply experimental data for design purposes. The results of this investigation that relate to the present report are given in reference 1 and in the reports listed in the bibliography.

This paper presents the aerodynamic characteristics of an NACA 0015 airfoil with a plain flap having a chord 30 percent of the airfoil chord (0.30c) and a straight contour from the flap nose radius to the trailing edge. The aerodynamic characteristics of the NACA 0015 airfoil with the "straight-contour flap" are compared with the aerodynamic characteristics, given in reference 1, of the same airfoil with a 0.30c plain flap having an airfoil contour from the flap nose radius to the trailing edge. This plain flap of reference 1 will be referred to in this report as the "airfoil-contour flap."

APPARATUS AND MODELS

The tests were made in the NACA 4- by 6-foot vertical tunnel described in reference 2. The test section of this tunnel has been converted from the original open, circular, 5-foot-diameter jet to a closed, rectangular, 4- by 6-foot throat for force tests of models in two-dimensional flow. A three-component balance system has been installed in the tunnel in order that force-test measurements of lift, drag, and pitching moment may be made. The hinge moments of the flap were measured with a special torque-rod balance built into the model.

The 2-foot-chord by 4-foot-span model (fig. 1) was made of laminated mahogany to the NACA 0015 contour (see table I), except that the 0.30c flap has a straight contour from the flap nose to the trailing edge. The nose radius of the flap was approximately one-half the airfoil thickness at the flap hinge axis. The gap at the nose of the flap was 0.005c and, for the sealed-gap tests, was filled with light grease.

The model, when mounted in the tunnel, completely spanned the test section except for small clearances at each end. With this type of installation two-dimensional flow is approximated, and the section characteristics of the airfoil and the flap may be determined. The model was attached to the balance frame by torque tubes that extended through the sides of the tunnel. The angle of attack was set from outside the tunnel by rotating the torque tubes with an electric drive. Flap deflections were set inside the tunnel by templets and were held by a friction clamp on the torque rod that was used to measure the flap hinge moment.

TESTS

The tests were made at a dynamic pressure of 15 pounds per square foot, which corresponds to an air velocity of about 76 miles per hour at standard sea-level conditions. The effective Reynolds number of the tests was approximately 2,760,000. (Effective Reynolds number = test Reynolds number X turbulence factor. The turbulence factor for the 4- by 6-foot vertical tunnel is 1.93.)

The flap was set, in increments of 5°, at deflections from 0° to 30° for tests with the gap both sealed and unsealed. For each flap setting, force tests were made throughout the angle-of-attack range at 2° increments from negative stall to positive stall. When either stall position was approached, the increment was reduced to 1° angle of attack.

RESULTS

Symbols

The coefficients and the symbols used in this paper are defined as follows:

c_l airfoil section lift coefficient (l/qc)

c_{d_o} airfoil section profile-drag coefficient (d_o/qc)

c_m airfoil section pitching-moment coefficient (m/qc^2)

c_h flap section hinge-moment coefficient (h/qc_f^2)

where

l airfoil section lift

d_o airfoil section profile drag

m airfoil section pitching moment about quarter-chord point of airfoil

h flap section hinge moment

c chord of basic airfoil with flap and tab neutral

c_f flap chord

q dynamic pressure

and

α_o angle of attack for airfoil of infinite aspect ratio

δ_f flap deflection with respect to airfoil

also

$$c_{l_\alpha} = \left(\frac{\partial c_l}{\partial \alpha_o}\right)_{\delta_f}$$

$$c_{l_{\alpha(free)}} = \left(\frac{\partial c_l}{\partial \alpha_o}\right)_{c_h = 0}$$

$$c_{h_\alpha} = \left(\frac{\partial c_h}{\partial \alpha_o}\right)_{\delta_f}$$

$$c_{h_{\delta_f}} = \left(\frac{\partial c_h}{\partial \delta_f}\right)_{\alpha_o}$$

The subscripts outside the parentheses indicate the factors held constant during the measurement of the parameters.

Precision

The accuracy of the data is indicated by the deviation from zero of lift and moment coefficients at an angle of attack of 0°. The maximum error in effective angle of attack at zero lift appears to be about ±0.2°. Flap deflections were set within ±0.2°. Tunnel corrections, experimentally determined in the 4- by 6-foot vertical tunnel, were applied only to lift. The hinge moments are probably slightly higher than would be obtained in free air and, consequently, the values presented are considered conservative. The increments of drag should be reasonably independent of tunnel effect, although the absolute value is subject to an unknown correction. Inaccuracies in the section data presented are thought to be negligible relative to inaccuracies that will be incurred in the application of the data to finite airfoils.

PRESENTATION OF DATA

Aerodynamic section characteristics of the NACA 0015 airfoil with a 0.30c straight-contour plain flap are presented as functions of lift coefficient in figure 2. The characteristics with the gap at the flap nose sealed are shown in figure 2(a) and the characteristics with the 0.005c gap are shown in figure 2(b). Part of the data in figure 2 are replotted in figure 3 to show the effect of gap on the variation of c_h with c_l for three typical values of angle of attack. Increments of section profile-drag coefficient caused by deflection of the flap are given as a function of flap deflection in figure 4.

The parameters for the straight- and airfoil-contour flaps are presented for comparison in table II.

AERODYNAMIC SECTION CHARACTERISTICS

Lift

Figure 2 indicates that the lift curves for various deflections of the straight-contour flap on the NACA 0015 airfoil are of the same general shape as those for the airfoil-contour flap on the same airfoil (reference 1). The angle of attack at which the airfoil stalled was about the same for both flap contours.

The slope of the lift curve c_{l_α} for the straight-contour flap was slightly larger than the slope for the airfoil-contour flap with the gap both unsealed and sealed. (See table II.) This increase may be attributed to the reduced thickness of the after portion of the airfoil which causes the flow more nearly to approach the theoretical flow for thin airfoils.

The effectiveness of the straight-contour flap in producing lift $\left(\frac{\partial \alpha}{\partial \delta_f}\right)_{c_l}$ was slightly less with the gap sealed and slightly greater with the gap unsealed than the effectiveness of the airfoil-contour flap with the same gap conditions. The straight-contour flap was effective in producing increments of lift at all flap deflections for all angles of attack at which tests were run. Because of separation phenomena, the effectiveness at large flap deflections was not so great as at small deflections.

With flap deflections and large angles of attack of opposite sense, the increment of lift coefficient due to flap deflection for the straight- and airfoil-contour flaps was greater with gap sealed than with gap unsealed; whereas, with flap deflections and large angles of attack of like sign, both unsealed and sealed gaps gave approximately the same value of lift-coefficient increment. (See fig. 2.) The curve of lift coefficient as a function of flap deflection for the straight-contour flap became nonlinear at flap deflections greater than 15° with the gap sealed and at flap deflections greater than 20° with the gap unsealed.

The parameter $c_{l_{\alpha(free)}}$ is a measure of control-free stability. The values of $c_{l_{\alpha(free)}}$ for the straight-contour flap were lower with the open gap and about the same with the sealed gap as the values for the airfoil contour flap (table II).

Hinge Moment of Flap

The flap hinge-moment curves (fig. 2) for the straight-contour flap are linear over a very small range of angles of attack. The curves of the airfoil-contour flap had the same general shape; that is, they were nonlinear over most of the test range.

The slope c_{h_α} and the slope $c_{h_{\delta_f}}$ for the straight-contour flap increased negatively over the corresponding values for the airfoil-contour flap. These increases in c_{h_α} and $c_{h_{\delta_f}}$ for the straight-contour flap are in qualitative agreement with the data of reference 3, which show that an increase in the thickness of the after portion of the airfoil caused a decrease in c_{h_α} and $c_{h_{\delta_f}}$; conversely, a decrease in thickness of the after portion of the airfoil, as in the straight-contour flap, should produce an increase in c_{h_α} and $c_{h_{\delta_f}}$.

The hinge-moment parameters for both gaps are given in table II. Because of the nonlinearity of the hinge-moment curves, the parameters c_{h_α} and $c_{h_{\delta_f}}$ measured at a flap deflection and an angle of attack of 0°, respectively, represent the curves over only a small range of angles of attack. The values of the parameters for unsealed and sealed gaps are indicative, however, of the relative merits of each arrangement. The theoretical effect of aspect ratio on the slopes of the curves for flap hinge moment is discussed in reference 4.

For small flap deflections at angles of attack of -8° and 0°, the straight-contour flap with sealed gap had a larger hinge-moment coefficient at a given lift than with the unsealed gap. (See fig. 3.) At all other angles of attack and flap deflections shown in figure 3, the hinge-moment coefficient for the straight-contour flap with the unsealed gap was greater than with the sealed gap. This characteristic is also true for the airfoil-contour flap (reference 1).

Pitching Moment

The slopes of the curves of pitching-moment coefficient as a function of lift coefficient at constant flap deflection and at constant angle of attack are shown in table II. The aerodynamic center was located approximately at the 0.23c station for the gaps both unsealed and sealed. This location of the aerodynamic center for the straight-contour flap is in close agreement with that for the airfoil-contour flap.

The aerodynamic center was expected to move toward the trailing edge because, in reference 3, an increase in the thickness of the after portion of the airfoil caused the aerodynamic center to shift forward; conversely, a decrease in thickness of the after portion of the airfoil should cause the aerodynamic center to shift toward the trailing edge. Apparently, the change in flap contour from airfoil to straight was too small to affect the location of the aerodynamic center.

When the circulation was varied by changing the effective camber of the airfoil, that is, by deflecting the flap, the aerodynamic center was at the 0.42c station with the gap unsealed and at the 0.41c station with the gap sealed. These locations agree approximately with those for the airfoil-contour flap. The location of the aerodynamic center for deflections of the flap is a function of aspect ratio (reference 4) and moves toward the trailing edge as the aspect ratio decreases.

Drag

Because of the unknown tunnel correction, the values of drag coefficients cannot be considered absolute; the relative values, however, should be independent of tunnel effect. Increments of drag coefficient, plotted as a function of flap deflection in figure 4, were determined by deducting the drag coefficient of the airfoil with the flap neutral from the drag coefficient with the flap deflected, with all other factors constant. At positive flap deflections and at angles of attack of 0° and $\pm 4^{\circ}$, the increment of drag coefficient was larger for the straight-contour flap with unsealed gap than with the sealed gap.

A comparison of figure 4 with figure 4 of reference 1 indicates that the increment of drag coefficient for the straight-contour flap was about the same as the increment for the airfoil-contour flap at low flap deflections.

In these tests, the minimum profile-drag coefficient, uncorrected for tunnel effects, was found to be 0.0131 for the straight-contour flap with sealed or unsealed gap. The airfoil-contour flap has a profile-drag coefficient of 0.0130 with the gap sealed and 0.0134 with the gap unsealed.

CONCLUSIONS

The results of tests of the NACA 0015 airfoil with a straight-contour plain flap having a chord 30 percent of the airfoil chord compared with the results of previous tests of the same airfoil with an airfoil-contour plain

L-365

flap of the same chord indicate the following conclusions:

1. The slope of the lift curve for the airfoil with the straight-contour plain flap was greater than for the same airfoil with the airfoil-contour plain flap.

2. The lift effectiveness of the straight-contour plain flap was slightly less with gap sealed and slightly larger with gap unsealed than the lift effectiveness of the airfoil-contour flap with the same gap conditions.

3. For the straight-contour flap, the variation of the flap hinge-moment coefficient with angle of attack and with flap deflection was larger than for the airfoil-contour flap.

4. The location of the aerodynamic center for the straight-contour flap was in close agreement with the location of the aerodynamic center for the airfoil-contour flap.

5. The airfoil had approximately the same drag characteristics for both flap contours.

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L-366

TABLE I. - ORDINATES FOR NACA 0015 AIRFOIL

[Stations and ordinates in percent of airfoil chord]

Station	Upper surface	Lower surface
0	0	0
1.25	2.37	-2.37
2.5	3.27	-3.27
5	4.44	-4.44
7.5	5.25	-5.25
10	5.85	-5.85
15	6.68	-6.68
20	7.17	-7.17
25	7.43	-7.43
30	7.50	-7.50
40	7.25	-7.25
50	6.62	-6.62
60	5.70	-5.70
70	4.58	-4.58
80	3.28	-3.28
90	1.81	-1.81
95	1.01	-1.01
100	(.16)	(-.16)
100	0	0
L. E. radius: 2.48		

TABLE II. - PARAMETER VALUES FOR 0.30c

STRAIGHT- AND AIRFOIL-CONTOUR PLAIN

FLAPS ON AN NACA 0015 AIRFOIL

	Straight-contour flap		Airfoil-contour flap	
Parameter	0.005c gap	Sealed gap	0.005c gap	Sealed gap
$\left(\frac{\partial \alpha_o}{\partial \delta_f}\right)_{c_l}$	-0.470	-0.560	-0.460	-0.580
$\left(\frac{\partial c_l}{\partial \alpha_o}\right)_{\delta_f}$	.090	.098	.089	.096
$\left(\frac{\partial c_l}{\partial \alpha_o}\right)_{free}$	.071	.081	.075	.080
$\left(\frac{\partial c_m}{\partial c_l}\right)_{\delta_f}$	.024	.017	.020	.020
$\left(\frac{\partial c_m}{\partial c_l}\right)_{\alpha}$	-.168	-.155	-.170	-.155
$\left(\frac{\partial c_{h_f}}{\partial \alpha_o}\right)_{\delta_f}$	-.0039	-.0028	-.0022	-.0023
$\left(\frac{\partial c_{h_f}}{\partial \delta_f}\right)_{\alpha_o}$	-.0084	-.0089	-.0063	-.0080

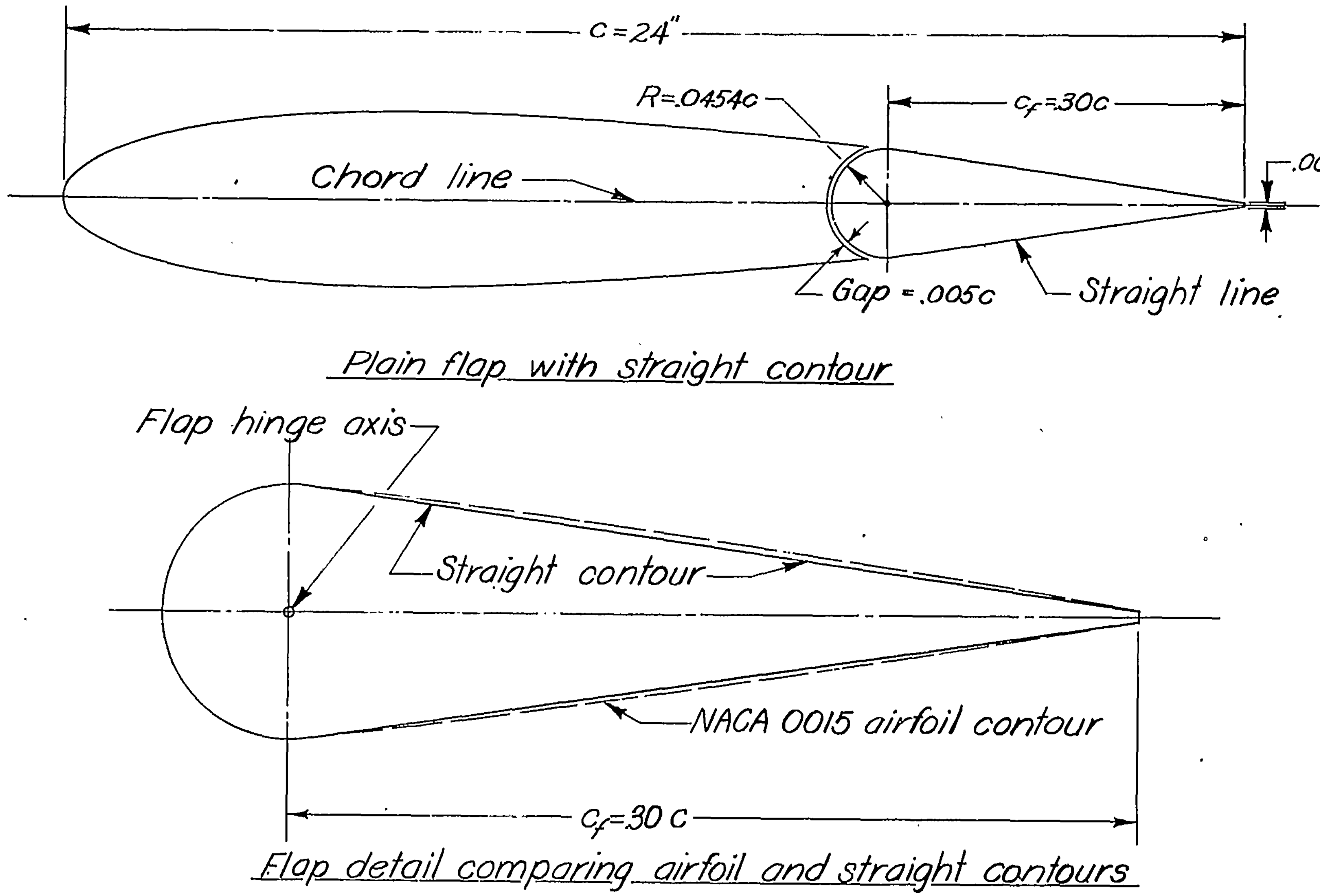
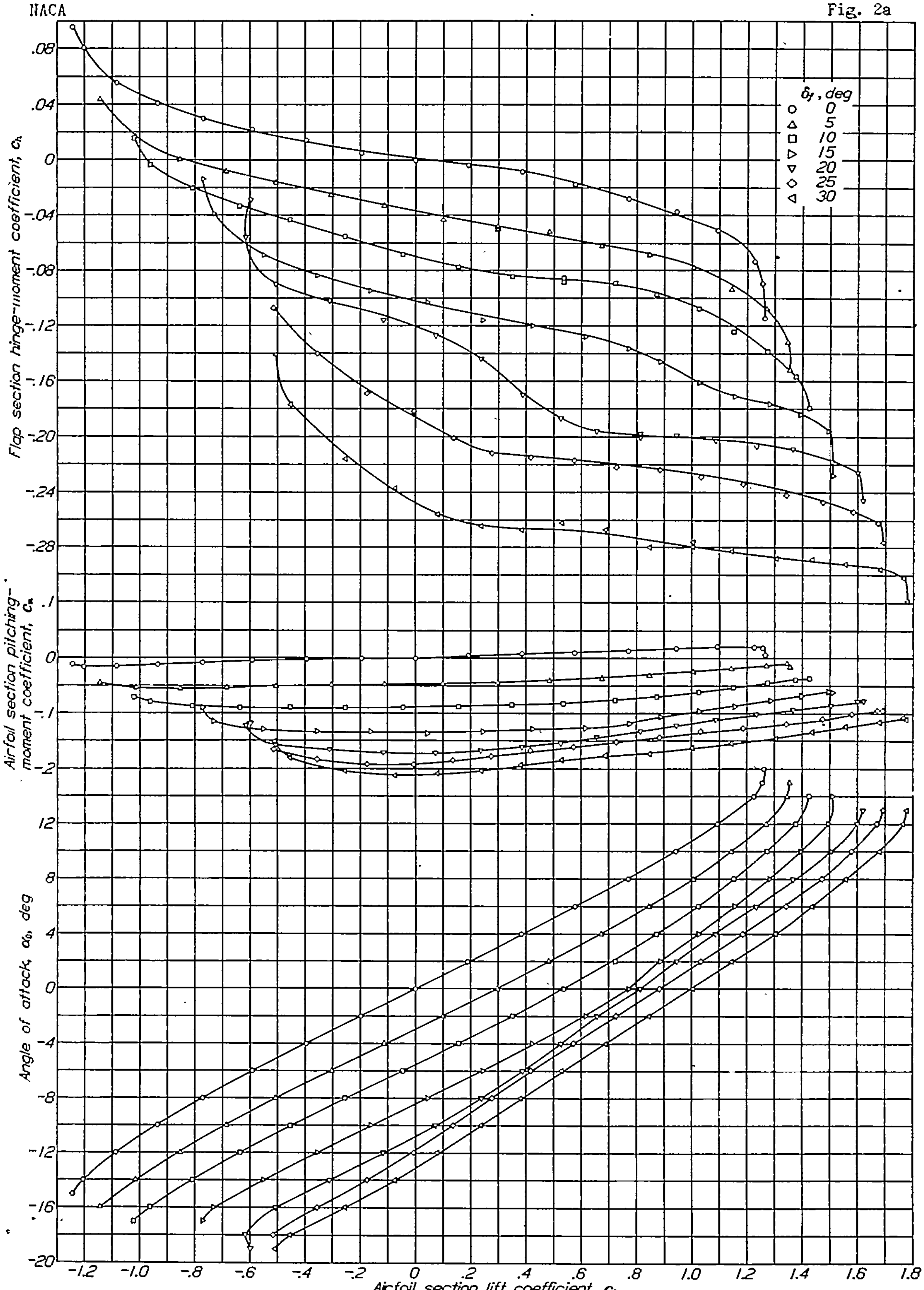


Figure 1.- Two-foot chord NACA 0015 airfoil with a 0.30c plain straight-contour flap.

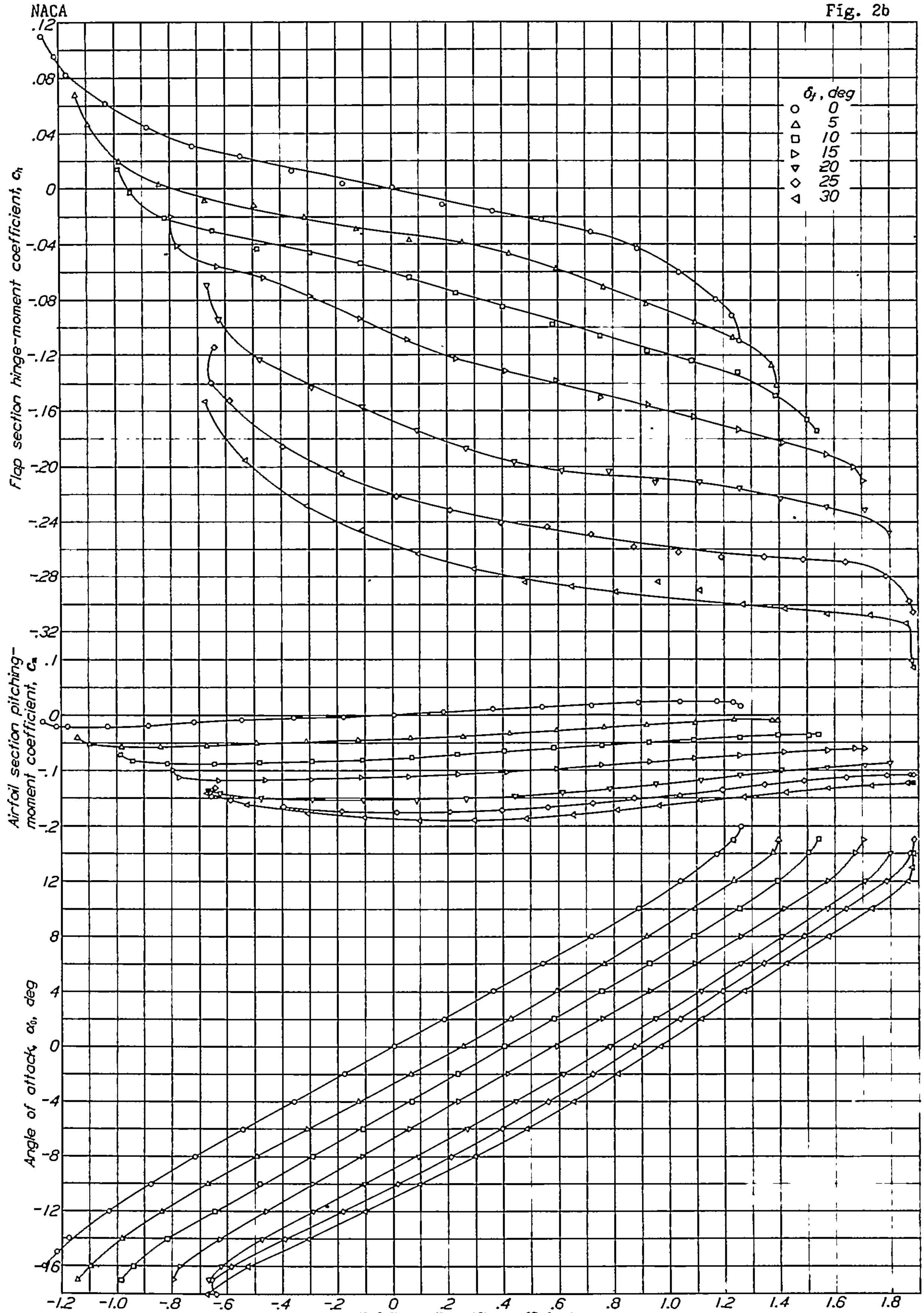
L-366



(a) Sealed gap

Figure 2(a,b).- Section aerodynamic characteristics of an NACA 0015 airfoil with a 0.30c straight-contour plain flap.

L-366



(b) 0.005c gap

Figure 2.- Concluded.

L-366

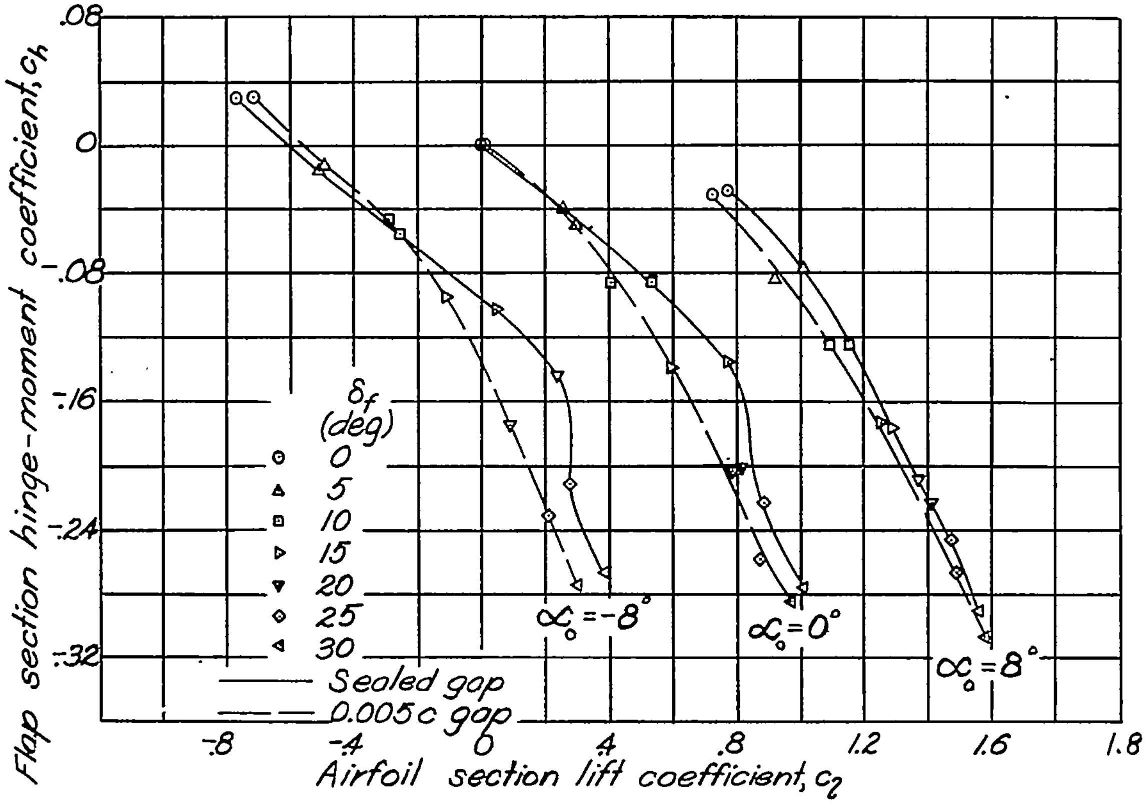


Figure 3.–Variation of flap section hinge-moment coefficient with airfoil section lift coefficient at several angles of attack and flap deflections. NACA 0015 airfoil. Plain flap with straight contour.

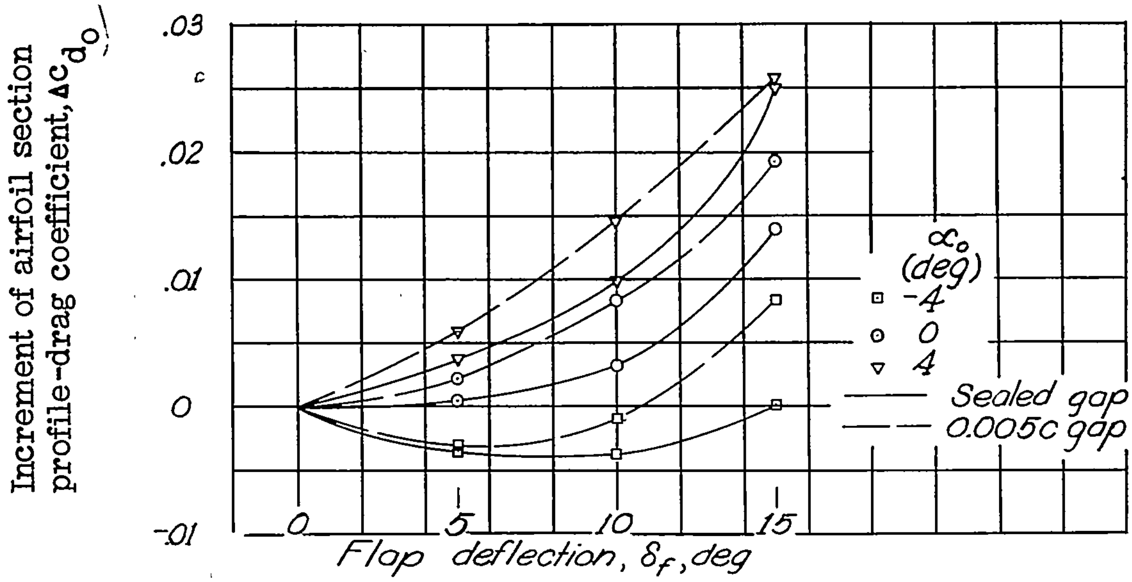


Figure 4.–Increment of airfoil section profile-drag coefficient as a function of the deflection of a 0.30c plain flap with straight contour.

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ABSTRACT

Aerodynamic section characteristics are presented for several flap deflections with sealed and unsealed gaps at the flap nose. Comparison between straight-contour flap and airfoil-contour plain flap shows that the former has a greater lift curve slope, slightly less effectiveness in producing increments of lift with nose gap sealed and slightly greater with gap unsealed, and larger variation of flap-hinge moment with angle of attack. Profile-drag characteristics were approximately the same for both types of flaps.

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